APPENDIX A

TRB RESEARCH PROBLEM STATEMENT

TRB Research Problem Statement

Submitted to the Transportation Research Board committees dealing with Pavement Maintenance (Committee A3C05) and Subsurface Soil-Structure Interaction (Committee A2K04) in January 1994

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A significant contributor to the deterioration of road pavements in urban areas is the repeated cutting of the pavement and excavation of pits and trenches for utility installation and repair. Although properly specified and executed backfilling techniques work well, these techniques often are not followed - especially on small projects. The result is an unsightly and uneven road surface which often causes earlier pavement replacement than would otherwise be the case. Techniques for repairing and installing utilities with only limited access from the surface are under rapid development. Often, however, they suffer from higher first costs than the alternative technique of trenching from the surface. In order to lower the overall cost to the public of maintaining both utilities and road pavements, it is necessary to have a means of estimating the statistical impact of a road cut on the life cycle cost of a pavement. When established, this indirect cost can be applied to utility pavement cut decisions in the same way as congestion costs and accident costs are applied to highway alignment decisions.

Objectives

1. To evaluate the available data from selected public works agencies on the history of road pavements under their control. The data would be evaluated to determine if the available data were sufficient to establish a relationship between the number, size, quality control, etc. of pavement cuts and the resulting pavement condition assessment and/or life. Neural network evaluation probably would be suitable for this assessment since it can be open-ended in terms of the parameters considered.

2. To define the data collection needs which would allow a better future evaluation of the relationships involved.

Key Words

Pavement repair, utility repair, utility installation, pavement maintenance, life cycle costing, trenchless technology.

Related Work

The U.S. National Committee on Tunneling Technology has identified trenchless technologies and microtunneling as having major potential impacts on the provision and repair of underground infrastructure in the U.S.

Europe and Japan are very actively engaged in developing these technologies and are also wrestling with the indirect cost issues. In the U.K, for example, recent legislation requires the consideration of the indirect costs of road work in terms of traffic congestion and other costs when such projects are planned. The North American Society for Trenchless Technology (primarily an industry group) is a focus for the developments in the technology in the U.S.

Urgency

This is an important cost issue for public works agencies and the public. The available data probably is not of the extent and quality desired for a thorough analysis but many public works managers intuitively understand there to be a relationship. It is important that current efforts at improving the data collection aspects of pavement management include this problem as an issue. This study would provide the necessary input to do this.

Cost

$200,000

THE EFFECT OF UTILITY CUTS ON THE SERVICE LIFE OF PAVEMENTS IN SAN FRANCISCO

Volume I: Study Procedure and Findings

STUDY CONDUCTED FOR THE

DEPARTMENT OF PUBLIC WORKS
CITY AND COUNTY OF SAN FRANCISCO
SAN FRANCISCO, CA 94103

BY

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FINAL REPORT
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EXECUTIVE SUMMARY

In 1992, the Department of Public Works (DPW) at the City and County of San Francisco contracted with the Engineering Design Center at San Francisco State University to study the effects of utility cuts on the service life of the City's pavements. The study included an examination of the City's Pavement Management System (PMS) database, the identification and implementation of means to refine the database, analysis of the database to quantify the effects of cuts on the service life, and a study of the current utility cuts practices.

From the PMS database which contained data on all the streets in the City, streets with special characteristics that could bias the aging process - such as failure to meet the City's acceptance standards and streets with rail tracks - were screened out. The remaining streets were grouped into five classes based on the pavement type and the traffic characteristics. The five classes are local asphalt streets with and without heavy-vehicle traffic, asphalt arterial streets with and without heavy-vehicle traffic, and concrete streets. Scatter diagrams showing Pavement Condition Score (PCS) versus age were developed for streets with few cuts (less than three), some cuts (between three and nine), and many cuts (more than nine). Following that, a linear regression curve was generated for each scatter diagram, and the regression results were used to study and analyze the aging behavior of each class of streets.

Asphalt pavements constituted more than 98% of the street sections used in this study. To demonstrate the over-all deterioration of asphalt pavements as a function of time, the regression coefficients of the four classes of streets studied were averaged to obtain an over-all deterioration curve for all asphalt streets in the City. This was done for the three levels of utility cuts, and the results are shown in Figure 1. Table 1 given below shows the useful life (Pavement Condition Score 65 - the condition at which re-surfacing is needed) for the three levels of cuts.

Table 1. Useful Life of all Asphalt Streets.

Streets with:	Useful Life (Years)
Less than 3 Cuts	26
Between 3 and 9 Cuts	18
More than 9 Cuts	13

The results show clearly that the pavement aging process manifested in lower pavement condition scores is accelerated by increased levels of utility cuts. Streets with 3 to 9 utility cuts are expected to require re-surfacing every 18 years which represents a 30% reduction in service life relative to streets with less than 3 cuts. Similarly, streets with more than 9 cuts are expected to require re-surfacing every 13 years which represents a 50% reduction in service life relative to streets with less than 3 cuts. The trends observed in the representative curves shown in Figure 1 were consistent with the individual results of all the five classes of streets analyzed. The results of the five classes of streets, as well as the results of the combined asphalt streets, demonstrated that the service life of the pavement is significantly reduced when the number of cuts is increased. As expected, arterial streets with heavy-vehicle traffic exhibited the largest reduction in service life, from 26 years for streets with fewer than three cuts to 17 years for streets with three to nine cuts (35% reduction), to 12 years for streets with more than nine cuts (54% reduction).

It should be noted that the City and County of San Francisco has one of the most stringent trench restoration requirements in the country. Permits for street excavations are required; the permitted backfilling materials and procedures are prescribed; and there is a three year moratorium on excavation in newly surfaced or reconstructed streets. Utility cuts produce damage that propagates beyond the area excavated; even the highest restoration standards do not remedy all the damage. Utility cuts cause the soil around the cut to be disturbed, cause the backfilled soil to be compacted to a different degree than the soil around the cut, and produce discontinuities in the soil and the wearing surface. Therefore, the reduction in pavement service life due to utility cuts is an inherent consequence of the trenching process.

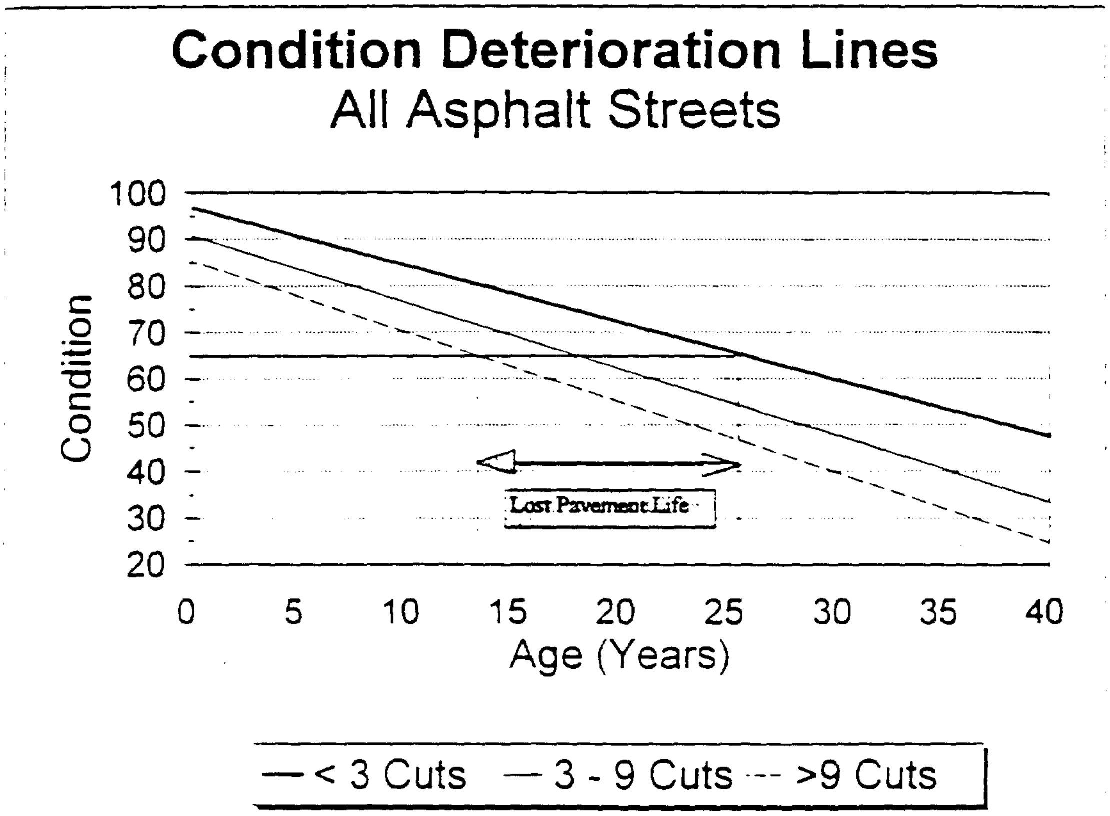

Figure 2. Condition Deterioration Lines of all Asphalt Streets

INTRODUCTION

In 1992, the Department of Public Works (DPW) at the City and County of San Francisco contracted with the Engineering Design Center at San Francisco State University to investigate the impact of utility cuts on the service life of pavements. The study spanned over a period of two years, and included an examination and refinement of the City's Pavement Management System (PMS) database, analysis of the pavement data, and the modeling of the pavement aging process for various pavement categories using linear regression.

There are approximately 850 miles of City streets maintained by the City of San Francisco, comprising 12,500 street sections and 195 million square feet of pavements. These pavements represent an investment in the City's infrastructure with a present worth of approximately $2 billion. The annual cost of maintaining the City's streets in 1989 was $13.4 million, but the recent annual maintenance costs are expected to be considerably higher than that due to inflation and deferred maintenance in previous years. To keep up with the needs for well maintained pavements at times of tight municipal budgets, the City has needs to study the aging behavior of pavements, identify the factors that accelerate the aging process, and quantify the contribution of these factors to the rate of pavement aging.

BACKGROUND

In 1984, the City and County of San Francisco developed a Pavement Management System (PMS) program to monitor the condition of the City's streets, to set maintenance priorities, and to aid in budgeting and forecasting fiscal needs. The street inventory contained in the PMS database includes, among other items, the following information:

Street Identification and Reference No.:
Street name, the two cross streets, and a PMS reference number.

Type of street:
A: Asphalt
C: Concrete
B: Brick
AC: Combination of asphalt and concrete
U: Undeveloped
S: Stairs or other non-driveables

Traffic Index:

5: Local streets without heavy vehicles traffic

6: Local streets with heavy vehicles traffic

7: Arterial streets without heavy vehicles traffic

8: Arterial streets with heavy vehicles traffic

Acceptance:

Has the street been accepted by the City for maintenance? Yes or No.

Street Geometry:

Street dimensions.

Last Paved:

Year when the street was last resurfaced.

Ride Quality:

A subjective estimate of the smoothness of the ride. The deduction factors are given in Table 2.

Cracking:

A factor describing the magnitude and extent of both fatigue and block cracking. The cracking values are given in Table 3.

Raveling (asphalt pavements):

A factor describing the extent and severity of surface wear which is manifested in the disintegration of the asphaltic concrete because of aging, usage, and the impact of the environment. The deduction values for raveling are given in Table 4.

Pavement Condition Score:

The Pavement Condition Score is computed using a perfect score of 100 minus the deduction factors for ride quality, cracking, and raveling for asphalt pavements, and only ride quality and cracking for concrete pavements. Therefore, the maximum condition score is 100 and the minimum is 0 for concrete pavements and -31 for asphalt pavements.

Pavement Cuts:

Prior to 1992, the PMS database contained the percentage of the street area comprised of cuts. Recently, the total number of cuts in the respective street section was entered under this category.

LITERATURE SEARCH

A literature search was conducted to gather information about other studies dealing with the impact of utility cuts on the performance of pavements. While there is a broad interest in the subject, very little was published.

In "Effects of Utility Cut Patching on Pavement Performance and Rehabilitation Cost, " A 1984-85 study conducted in Burlington, Vermont, was presented. The study involved paired analysis of the pavement condition of patched vs. non-patched pavements. The study was conducted on randomly selected streets representing all ages and functional classifications. The study involved both a visual survey to calculate the Pavement Condition Index (PCI) and a Falling Weight Deflectometer (FWD) to measure deflections corresponding to a simulated truck wheel load.

Three methods were used. The first method calculated the rate of deterioration (average loss in PCI per year) for both patched and non-patched pavement sections. The study has shown that patched sections have a much steeper deterioration rate than non-patched sections, especially for streets with a high terminal PCI. For a terminal PCI of 70, the average life of patched sections was 11.6 years whereas the average life of unpatched sections was 20.1 years. The second method used least square linear regression of PCI with respect to pavement age. From this undertaking, it was found that on average patched sections reached PCI value of 70 at the age of 12.1 years whereas unpatched sections reached PCI value of 70 at the age of 19.8 years. The third method used a third degree best fit curve to relate PCI to pavement age. The results obtained show that the average life of patched sections is 8.5 years whereas the average life of unpatched sections is 25.9 years.

The study did not present a quantitative measure of the goodness of the fit of the curves derived, and there was no discussion of the adequacy of the limited data used to provide statistically significant conclusions. Despite these limitations, the three methods used in the study, although different, all pointed to one conclusion: Patched pavements require resurfacing much more frequently than unpatched pavements.

A California county performed a condition score versus age study using 122 street sections up to 22 years of age. The scatter diagram showed considerable variation in the Pavement Condition Index (PCI) for pavements of the same age. For example, for a specific age, the PCI ranged from 90 to 45. A second degree polynomial curve was fitted to the data producing the following regression equation:

$$PCI = 99.126 - 1.932\,(age) - 0.019\,(age^{**}2)$$

However, no justification was given for selecting the second degree polynomial curve, the street sections were not grouped into classes of similar characteristics, and the regression curve did not appear to be the best fit for the data point shown.

In "Pavement (Maintenance) Management Systems," a good discussion of pavement performance and optimal maintenance strategies was presented. The study contains a frequently cited pavement life cycle curve showing the condition of the pavement versus time and the approximate cost of renovation at various condition levels. The curve is shown in Figure 2. While the information illustrated in the curve makes sense and reflects the logical behavior of pavements, the study provided neither information on how the curve was derived nor justification for it.

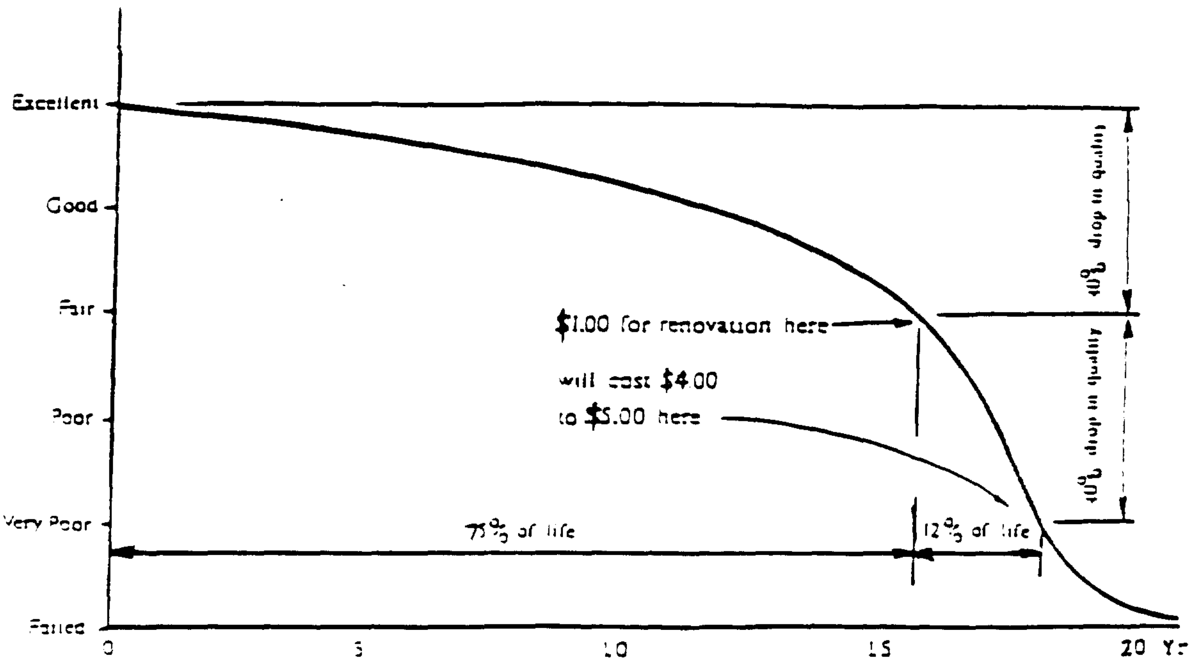

Figure 2. Pavement Life Cycle (Reprinted from APWA Reporter, November 1983)

In "Estimating the Life of Asphalt Overlays Using Long-Term Pavement Performance Data," a mathematical model for predicting the performance of asphalt overlays was developed using overlay thickness, traffic volume, maintenance patching, and initial design life as independent variables. The model developed is expressed in the following equation:

A = 1.32 x B**0.33 x T**0.47 x E**-0.097 x 1.14**P

where

A = Duration of overlay life cycle corresponding to the terminal pavement condition rating (PCR) of 55 years,

B = Duration of initial pavement structure life cycle corresponding to the terminal PCR level of 55 years,

P = Patching factor, a numeric amount of 0 is used for no or limited patching, and 1 is used for all other cases,

T = Thickness of overlay (mm), and

E = Number of equivalent single axle loads per day calculated using the following equation:

E = (ADT83 x PT x TF x LDF) / 200

where

ADT83 = Average daily traffic in 1983,

PT = Percentage of trucks,

TF = Truck factor, and

LDF = Lane factor.

METHODOLOGY OF STUDY

The following tasks were completed in the execution of this study:

1. Overview of the PMS database:
The data base was explored and examined for any irregularities that warrant additional investigation.

2. Site investigations:
The data entries identified in Task 1 were checked and verified by site visits to the streets' locations.

3. Refinement of the PMS database:
The results of Task 2 were incorporated into the database. Additionally, the database contained a substantial number of streets that were not officially accepted by the City for maintenance. These streets were visited by members of the research team and the DPW staff to determine their suitability for acceptance; and the actions taken on these streets were incorporated into the database.

4. Data Screening:
Street sections with missing or old key data or characteristics that would bias the results were discarded. Unaccepted streets, streets with rail tracks, and streets older than 40 years were discarded because of the following reasons:

i. Unaccepted streets did not meet the City's design requirements, and are likely to deteriorate at rates different from streets that meet the City's design requirements.

ii. Streets with tracks will have ride quality scores different from identical streets without tracks. Moreover, the presence of tracks and the associated vehicular use of these tracks will probably cause the pavements to deteriorate at rates different from streets similar in all respects but without racks.

iii. Some of the information pertaining to very old streets (older than 40 years) was judged to be questionable because it was believed that some records pertaining to these streets were not updated as the status of the streets changed. In particular, few pavements appeared to be not as old as the records showed and were probably resurfaced at a later date without an update of the records. The records for the rest of streets (40 years old or less) seemed to be much more accurate.

iv. Streets that were slurry sealed (an inexpensive treatment that enhances the pavement condition but does not restore it to reconstruction levels) were not used in this study because these streets will deteriorate in a different fashion than streets that were reconstructed.

Since there was plenty of reliable data available for the study, the study was strengthened by discarding a few data entries that were either likely to cause bias or did not seem to be very reliable. The data used in this study are summarized and presented in Volume II.

Table 2. Ride Quality Deduction Factors

CLASSIFICATION	DEDUCTION FACTORS
Acceptable	0
Tolerable	25
Unacceptable	60

Table 3. Cracking Deduction Factors

	DEDUCTION FACTORS EXTENT (%age of Area)			
SEVERITY	**None**	**1-25**	**26-50**	**>50**
None	0	0	0	0
Acceptable	0	5	10	15
Tolerable	0	13	19	26
Unacceptable	0	23	30	40

Table 4. Raveling Deduction Factors

	DEDUCTION FACTORS EXTENT (%age of Area)			
SEVERITY	**None**	**1-25**	**26-50**	**>50**
Acceptable	0	4	8	12
Tolerable	0	11	16	21
Unacceptable	0	18	24	31

5. Linear regression:
Twelve scatter diagrams were prepared for asphalt streets representing all four traffic index classifications (5, 6, 7, and 8) and three extents of cuts (few, some, and many cut). For asphalt pavements, few cuts represented fewer than three, some represented three to nine, and many represented ten or more cuts per street section. These limits were arbitrarily selected to warrant proper data distribution for all categories. The sample size of the concrete streets in the final database was 128 entries. It was not possible to breakdown these streets into four TI classifications and three levels of cuts because that would have produced very small samples which would have been inadequate for regression analysis. Instead, two scatter diagrams for concrete sections belonging to all four TIs were prepared: one for sections with few cuts (less than 5) and the other for sections with many cuts (5 or more).

Linear regression analysis was done on the data of each scatter diagram, and fourteen linear equations relating condition score were derived for the following fourteen situations:

TI-5 Asphalt Pavements with few, some, and many cuts
TI-6 Asphalt Pavements with few, some, and many cuts
TI-7 Asphalt Pavements with few, some, and many cuts
TI-8 Asphalt Pavements with few, some, and many cuts
All TIs concrete Pavements with few and many cuts

The results of the regression analysis and the scatter diagrams, along with the regression lines, are given in Appendix II.

6. Analysis of the Impact of Cuts on Performance:
For each traffic index (asphalt pavements), the three regression lines for few, some, and many cuts were plotted and compared. The four curves are given in Appendix I. For concrete pavements, the regression lines for few and many cuts were also plotted and compared. The results are also given in Appendix I.

ASSUMPTIONS & LIMITATIONS

1. The study did not analyze the deterioration as a function of time and the extent of cuts on a specific pavement. That approach would have been impractical because it would take 40 years to track the performance of a pavement over a 40 year period.

2. Age, dimensions (area and shape), and restoration techniques were not identified. Although these factors would make a difference if the study examined the deterioration with time of specific pavements, they are insignificant when an over-all evaluation is conducted as was the case in this study.

3. The study did not account for variations in the restoration methods used. However, it is believed that these variations are quite minor since restoration must follow the City's stringent standards.

4. The study did not account for the characteristics of the soils supporting the pavement. Again, this is not believed to be a serious limitation because the pavement design and the cut restoration standards provide provisions to neutralize this factor.

5. The study was conducted using data pertaining to streets in the City and County of San Francisco. Although, the broad conclusions are likely to agree with results in other locations, the results obtained in this study are specific to San Francisco.

6. The scatter diagrams given in Appendix II show that different diagrams have different concentration regions of the data points. Since the number of utility cuts per pavement section normally increases with time, the regression curves for each traffic index should be expected to have different data concentration regions. The curves for pavements with few cuts usually reflect pavements with a large portion of recently paved surfaces, and the curves for pavements with many cuts normally reflect pavements with older surfaces.

RESULTS

The linear regression graphs for both asphalt and concrete pavements are given in Appendix I. The scatter diagrams with the linear regression curves are given in Appendix II. The regression analysis results are tabulated in Appendix II. For asphalt pavements, each graph shows the three regression lines for few cuts (less than 3), some cuts (3 to 9), and many cuts (more than 9) plotted in the same graph. For concrete pavements, because of the limited number of such streets in the city, it was possible to produce only one combined graph for all TIs which used two levels of cuts: few (less than 5) and many (5 or more). As shown in the regression results table in Appendix II, the coefficient of correlation, C, between age (independent variable) and the Pavement Condition Score (dependent variable) was around 0.5 for all 14 sets, with a minimum value of 0.39 and a maximum value of 0.71. The correlation coefficient is a measure of how much variation in the dependent variable is attributed to the variation of the independent variable. As shown in the graphs in Appendix I, there is a strong and consistent trend for pavements with cuts to deteriorate faster than similar pavements but with fewer cuts. This trend applies without exception to all the five classes of street sections considered.

To demonstrate the impact of utility cuts on the aging process of pavements, the average number of cuts for the data used for each regression line was calculated, and the number of years it would take a pavement of the same type and TI to reach a PCS level of 65 (the condition at which resurfacing is needed) were computed from the regression equations. The results are given in Table 5. For example, a TI-5 asphalt pavement will normally reach PCS 65 in 28 years if there were less than 3 cuts in the section. However, the age till

PCS 65 will drop to 18 years for pavements with 3 to 9 cuts, and will drop to 14 years for pavements with more than 9 cuts per section. It should be noted that the pavement age till PCS 65 shown in Table 5 are average values, and that some pavements will have longer lives than predicted by the models and other pavements will have shorter lives.

Table 5. Projected Age of Pavements till PCI 65
for the Shown Levels of Cuts

	TI	Type	AVERAGE CUTS	AGE TILL PCI 65
Few			0.7418	28
Some	5	Asphalt	5.3754	18
Many			22.5527	14
Few			0.7386	22
Some	6	Asphalt	5.1590	17
Many			18.5562	12
Few			0.5714	29
Some	7	Asphalt	5.5191	20
Many			18.5048	15
Few			0.6433	26
Some	8	Asphalt	5.1271	17
Many			16.3353	12
Few	ALL	Concrete	1.3210	26
Many			12.9149	15

Average Cuts: The average number of cuts for street sections in the corresponding category.

Age till PCI 65: Projected age of pavement when the pavement condition index reaches 65 using the derived regression equation.

PCI: Pavement Condition Index

The results show uniform trends for all regression lines, and clearly indicate that streets with few cuts deteriorate more slowly than streets with some cuts, and streets with some cuts deteriorate more slowly than streets with many cuts for both concrete and asphalt pavements and for all TIs. This trend is also in line with the engineers' expectation that streets with heavy-vehicle traffic will have lower lives than streets without heavy-vehicle traffic.

The percentage reductions in service life for pavements with few cuts (3 to 9) and many cuts (more than 9) relative to pavements with less than 3 cuts are given in Table 6. For concrete streets, pavements with many cuts (5 or more) had a 42% reduction in service life relative to pavements with less than five cuts.

Table 6. Percentage Reduction in Life due to Cuts of Asphalt Pavements.

	Percent Reduction in Pavement Life Relative to Pavements with Less than 3 Cuts	
TI	**3 to 9 Cuts**	**10 or More**
5	33	48
6	23	45
7	31	48
8	35	54
Average	30	50

To demonstrate the over-all deterioration of asphalt pavements as a function of time, an over-all deterioration curve for all asphalt streets in the City was developed for each of the three levels of utility cuts. The curve is given in Appendix I. The over-all regression coefficients were obtained by calculating the mean values of the regression coefficients of the four classes of streets studied. The useful life (Pavement Condition Score 65 - the condition at which re-surfacing is needed) for the three levels of cuts was calculated from the regression equation, and is given in Table 7.

Table 7. Useful Life of all Asphalt Streets.

Streets with:	**Useful Life** (years)
Less than 3 Cuts	26
Between 3 and 9 Cuts	18
More than 9 Cuts	13

Lastly, it can be argued that the results obtained from this study are relatively conservative and may be underestimating the damage caused by utility cuts. Street sections with many cuts are usually older streets with relatively minor traffic volumes that do not require more frequent surfacing. Therefore, the extent of the damage might be under-exposed because the limited traffic on such streets will help slowdown the rate of aging.

CONCLUSION

The results clearly indicate that utility cuts do indeed cause pavements to age faster than pavements with no or fewer cuts, and require the streets to be resurfaced at more frequent intervals. As shown in Table 7, the pavement aging process manifested in lower pavement condition scores is accelerated for increased levels of utility cuts. Asphalt streets with 3 to 9 utility cuts are expected to require surfacing every 18 years which represents a 30% reduction in service life relative to streets with less than 3 cuts. Similarly, streets with more than 9 cuts are expected to require re-surfacing every 13 years which represent a 50% reduction in service life relative to streets with less than 3 cuts.

The trends observed in the representative curves shown in Figure 1 were consistent with the individual results of all the five classes of streets analyzed. The results of the five classes of streets, as well as the results of the combined asphalt streets, demonstrated that the service life of the pavement is significantly reduced when the number of cuts is increased. As expected, arterial streets with heavy-vehicle traffic exhibited the largest reduction in service life, from 26 years for streets with fewer than three cuts to 17 years for streets with three to nine cuts (35% reduction) and to 12 years for streets with more than nine cuts (54% reduction).

The City and County of San Francisco has one of the most stringent trench restoration requirements in the country. Permits for street excavations are required; the permitted backfilling materials and procedures are prescribed; and there is a three year moratorium on excavation in newly surfaced or reconstructed streets. Consequently, the reduction in the pavement service life due to utility cuts is a natural consequence of the excavation and backfilling process, and can not be eliminated by stringent excavation control. Utility cuts produce damage that propagates beyond the area excavated; even the highest restoration standards do not remedy all the damage. Utility cuts cause the soil around the cut to be disturbed, cause the backfilled soil to be compacted to a different degree than the soil around the cut, and produce discontinuities in the soil and the wearing surface. Therefore, the reduction in pavement service life due to utility cuts is an inherent consequence of the trenching process.

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